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## "Neo" Magnets Can Add Value to Motors

Neodymium-iron-boron (Neo) can be used in place of ferrite magnets to improve the power density of a d.c. motor, while simplifying its manufacture.

Traditionally, small appliances are driven by universal motors, but when battery operation is required, better power density and efficiency are achieved if a permanent magnet field system is used. Until recently, though, these motors have continued to use quite conventional technology, such as mechanical commutator systems and sintered ceramic ferrite magnets. This article describes an improved magnet material that is now supplanting ferrite and illustrates the cost and performance benefits to be gained.

Neodymium-iron-boron (Neo) is a permanent magnet alloy which inherently has a much higher energy density than ferrite. This attribute, when correctly applied to a motor's design, can provide it with a better power density, an improved motor efficiency, or some combination of the two. Higher power density can be utilized as a greater output torque, resulting in a higher performance device. However, it can also be used to make the motor a smaller, lighter component. Of course, battery life is a direct result of the motor having a higher efficiency via a lower current draw.

### Optimum Utilization of Bonded Neo

The energy density of Neo is in fact so much higher than that of ferrite that it can afford to be diluted as it is consolidated from powder into a permanent magnet. It is particularly versatile in bonded form, blended either with Nylon or PPS into a compound for injection-molding, or with epoxy for compression-molding. As demonstrated later in the article, bonded magnets offer particular constructional advantages within a small motor, compared to the sintered ceramic form in which ferrite is generally employed.

A typical construction for rotor and stator of a conventional permanent magnet appliance motor is shown in Figure 1, together with its cross-sectional geometry illustrated as a magnetic flux distribution which was calculated at rated output using finite element analysis (FEA). This armature has the minimum practical number of winding slots (five), the commutator being below this (and not visible). The stator comprises the motor's housing, into which the two ceramic ferrite magnet arcs are glued; in some variations of this motor, the magnets are attached using clips.

Regions in the FEA flux distribution in Figure 1 that are shown in red indicate that magnetic saturation is occurring, in which case an increase in the magnets' energy will not provide the expected motor performance benefits. Clearly, the critical regions in the magnetic circuit are the spokes of the armature teeth and the housing (equidistant between the magnet arcs). For this reason, a "direct" substitution of a bonded Neo magnet for these ceramic ferrite arcs is possible, but usually not recommended. Optimum use of a higher energy magnet first requires adjustment to the outer radius of the magnets (also the inner radius of the housing), typically to reduce the magnets' thickness while increasing the housing's thickness. Secondly, the spokes of the armature teeth may be widened to accommodate extra flux, though the slots may then need to be reshaped to retain the space needed for the winding.

*Figure 1. Rotor and stator of a d.c. appliance motor, with FEA flux distribution at rated output.*

### Choice of Magnetic Properties

Many small appliance motors are designed to run relatively hot, and the consequent continuous operating temperature of a bonded Neo magnet will determine not only what binder must be used, but also the grade of Neo powder that can be employed. Because ingredients must be added to neodymium-iron-boron to stabilize it more than approximately 160°C, there is a trade-off between a magnet's energy density and its operating temperature. Coincidentally, this is about the same temperature above which a binder such as PPS must be employed rather than Nylon, and it is unfortunate that the maximum loading achievable with PPS for injection-molding is somewhat lower than with Nylon; this, too, affects the energy density of the magnet.

The measure of a permanent magnet's magnetic performance is demonstrated by a pair of demagnetization characteristics, which plot its flux density (B) and magnetization (B – H) against its magnetizing force (H). The flux density that remains when H=0 is known as the remanence of the material, while the (de)magnetizing force (–H) that a material can withstand before its magnetization (B – H) is brought to zero is known as its intrinsic coercivity; these parameters are commonly used as figures of merit for a permanent magnet.

Figure 2 gives some examples of demagnetization characteristics, with the upper curve of each pair being the magnetization (B – H), and the lower curve being the flux density (B).

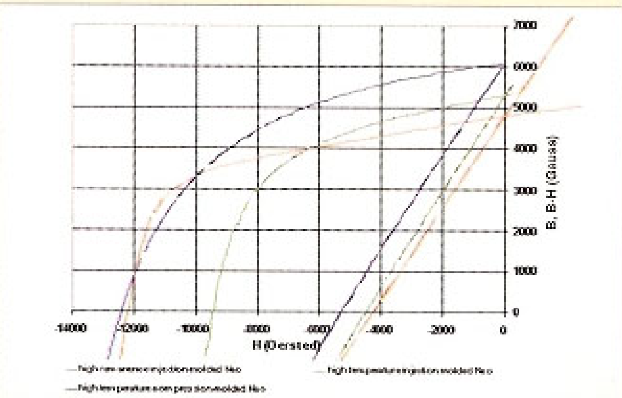


*Figure 2. Demagnetization characteristics of some bonded Neo magnet materials.*

Of the two injection-molded materials shown in Figure 2, the "high remanence Neo" will provide the greatest improvement both in the magnet's flux and in its energy density compared to a conventional ceramic ferrite (which has a typical remanence of 4,200 Gauss). To stabilize injection-molded Neo for operation more than approximately 160°C, the "high temperature" Neo has a significantly enhanced intrinsic coercivity provided by modifying its composition, but this, together with the introduction of PPS binder, slightly reduces the remanence. The higher loading achieved for compression-molded Neo yields a substantial magnetic advantage over ceramic ferrite, even at high temperature.

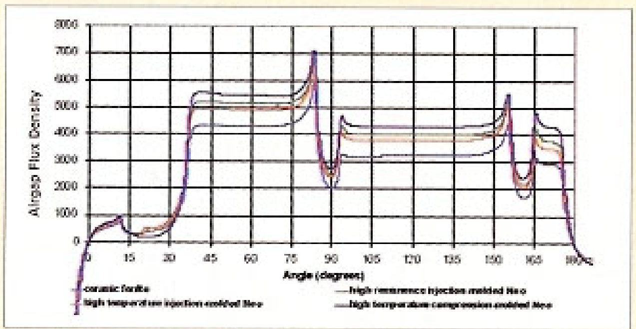


*Figure 3. Air gap flux density distributions in appliance motor at rated output.*

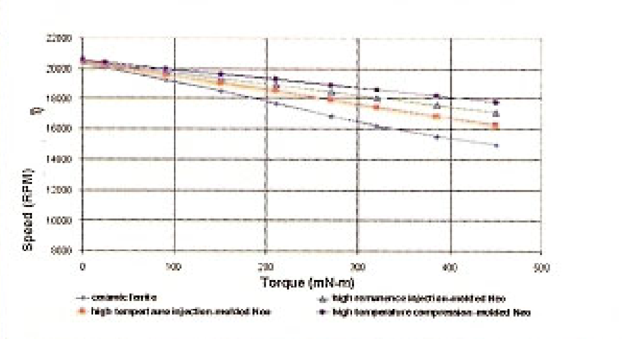


*Figure 4. Speed vs. torque curves for d.c. appliance motor using various permanent magnet materials.*

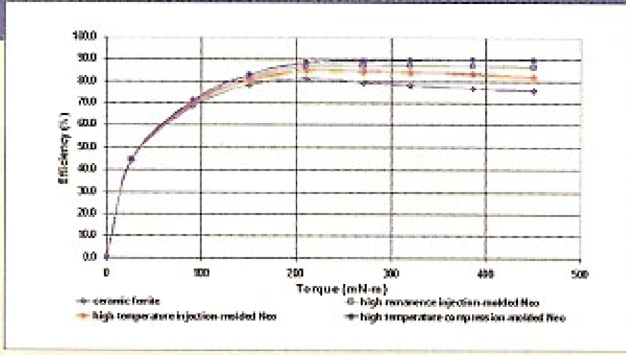


*Figure 5. Efficiency vs. torque curves for d.c. appliance motor using various permanent magnet materials.*

With the magnetic circuit modified for optimum use of the higher energy Neo materials, the resulting flux density can be raised significantly as shown in Figure 3. These curves are plotted over one pole pitch (180 degrees) around the motor's air gap, and they illustrate the effects of armature slots and a demagnetization field at rated winding current. If operation of the magnets at temperatures of 160°C or more is likely, then motor performance is clearly enhanced by using injection-molded Neo over ceramic ferrite and by using compression-molded over injection-molded Neo. However, if such high temperatures will not be reached, then selection of a high remanence Neo powder will likely provide a significant enough performance improvement as an injection-molded component.

## Lower Cost Assembly with Bonded Neo

Whether the ceramic ferrite magnets in this motor are glued or retained by clips within the housing, this use of two individual magnet arcs represents an unwanted element of assembly cost and a lack of structural integrity. Any bonded magnet solution clearly improves both of these factors and is an added value provided by the Neo materials.

While both injection- and compression-molded magnets can be provided as individual arcs like ceramic ferrite, the more common solution is to make them as complete ring assemblies for direct mounting within the motor's housing. A compression-molded Neo ring can be pressed to fit within the housing and either glued or locked in place using tabs. An alternative approach, which is well suited to injection-molding, is a design in which a steel ring is insert-molded, allowing the Neo magnet material to be used only in the desired magnetic pole arc regions. This ring component can then be fitted within the housing and may also provide the increased cross-sectional area needed to prevent magnetic saturation from occurring in the housing. Of course, the housing itself may be insert-molded, although in many cases either its dimensional tolerances or its features prevent this.

## Improvements to the Motor's Power Density

Assuming that we are looking for the optimum use of a higher energy bonded Neo magnet, both the motor's housing and its armature teeth will be re-sized to accommodate the extra flux. Because of this, the motor torque constant (Kt) will be greater than with ceramic ferrite magnets, providing more output torque per ampère of current. The winding resistance may also fall (fewer turns of a slightly thicker wire), raising both the current and the torque, but this is usually adjusted to provide the desired speed versus torque characteristic for the motor. Figure 4 shows these curves on the basis of keeping no-load speed about the same for all four magnet materials. Look at any particular speed (horizontal line), and notice how the torque increases significantly as additional flux is provided by the bonded Neo magnets, a ratio of more than 2:1 from ceramic ferrite to compression-molded Neo.

Alternatively, it may be more desirable to utilize the extra flux to lower the current draw and have a more efficient electric motor. The efficiency characteristics are shown in Figure 5, and notice that any desired torque (vertical line) is provided at a higher efficiency using the bonded Neo magnets. At rated output, motor efficiency is improved by more than 10 percent from ceramic ferrite to compression-molded Neo. In most practical cases, if the higher energy density of a bonded Neo magnet is to be used to improve motor performance, the design will provide some combination of increased output torque and efficiency and a compromise between these two parameters.

The preceding characteristics all relate to using different magnets in similar-sized motors. One other option is to utilize the gain in power density to provide a motor which is smaller and lighter, keeping its performance largely unchanged. A shorter stack length has the added benefit of reducing material costs. The ceramic ferrite version of this motor had a stack length of 48 mm, which is successively reduced by redesign with higher energy bonded Neo magnets to less than 34 mm in the case of compression-molded Neo (see Table 1).

## Conclusion

There are several ways in which bonded Neo magnets can add value to the motors used in small appliances. The d.c. motor will have a greater power density, which can provide some combination of a higher efficiency, a lower current draw, a higher output torque, and a reduction in size; in turn, size may be reduced via motor length, diameter, or some combination of these two. Meanwhile, manufacture of the stator and magnet assembly may be simplified, reducing this cost. What is clear is that the optimum benefits from bonded Neo cannot be obtained by its "direct" substitution for ceramic ferrite, but can be achieved with relatively minor redesign of the magnetic circuit components.

*This information is provided by Dr. Peter Campbell, vice president of Technology, and Anthony C. Morcos, senior scientist, Magnequench Inc., Research Triangle Park, NC.*

Circle No. 114

| Magnet Type | Stack Length |
|---|---|
| Ceramic Ferrite | 48.0 mm |
| High Temperature Injection-Molded Neo | 39.2 mm |
| High Remanence Injection-Molded Neo | 36.9 mm |
| High Temperature Compression-Molded Neo | 33.8 mm |

*Table 1. Reduction in stack length by d.c. appliance motor using various bonded Neo magnet materials.*